• Engineering Geology
• Coastal Geology
• Hydrogeology

Nolan, Zinn, and Associates

DRAFT TECHNICAL SUMMARY FOR GEOLOGIC FEASIBILITY INVESTIGATION

Proposed Visitor Center For Monterey Bay National Marine Sanctuary
Four Sites
Monterey Bay Region, California

Job #02037--SC
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Summary Of Geologic and Geotechnical Engineering Hazards

	Probability Of Occurrence			
Potential Geologic & Geotechnical Hazard	**Monterey Train Depot**	**Fun Spot**	**Beach Boardwalk**	**Seacliff State Beach**
Seismic Shaking	High	High	High	High
Liquefaction	High	High	High	Low
Lateral spreading	Low To High[1]	Low To High[1]	Low To High[1]	Low
Consolidation Settlement	Moderate To Low	Moderate To Low	Moderate To Low	Low
Fill Settlement	Moderate To Low	Moderate To Low	Moderate To Low	Low
Expansive Soils	Low	Low	Low	Moderate
Slope Failure	Not applicable	Not applicable	Not applicable	Low to high[2]
Cliff Erosion	Not applicable	Not applicable	Not applicable	Low to high[2]
Beach Erosion	Low	Low	Low To Moderate	Low
Shallow Ground Water	High	High	High	Low
Salt-Bearing Ground Water	High	High	High	Low
Flooding	Low To Moderate	High	Low[3]	Low
Tsunami	Indeterminate	Indeterminate	Indeterminate	Low

EXECUTIVE SUMMARY

Overview

We have attempted to perform a preliminary characterization of the potential hazards and associated risks to the prospective visitor center sites, in spite of the fact that there are no site-specific plans for any of the sites. The difference between hazards and risks are an important distinction to make for this project. A hazard is defined as the expected occurrence of an event. The risk is defined as the expected consequences of these future events. Obviously, the evaluation of the likelihood of adverse events is only an intermediate step toward the goal of assessing the consequences of such events.

Reduction of risk associated with geologic and geotechnical hazards involves careful design and construction of structures. Past experience has shown that quality of design and construction is almost as important as the precise evaluation of geologic and geotechnical engineering parameters.

It is important to note that after studying all four prospective sites, we have concluded that they are all feasible from a geologic and geotechnical perspective, provided that the recommended site-specific design studies are performed, and the hazards are adequately mitigated.

After reading this technical summary, it is possible that layman readers may form the impression that all of the selected sites are unusually hazardous, based upon our characterization. This is not the case, since, in our experience, most of the hazards encountered at each site for this study are ubiquitous to properties on the coastline in central California. Indeed, the reader may note the striking similarities in the potential hazards at each site, in spite of the large distances between the sites. This is controlled largely by the rise and fall of sea levels and the gradual tectonic uplift of the coastline over geologic time. It is unlikely that a geologic-hazards free candidate site for the visitor center that meets all the other requisite needs can be found in this region.

City of Monterey - Monterey Historic Train Depot

Site Conditions

The Monterey Historic Train Depot is a relatively flat site set amidst a set of train tracks, slightly south of the Monterey Bay coastline. The Depot building is surrounded by large parking lots. A seawall, located north of the Depot property, protects developments in this area from erosion and coastal flooding due to storm-waves.

The Depot site is mapped as being underlain by artificial fill by previous researchers. A prior geotechnical engineering report, prepared for the Monterey Sports Center, located south of the site, across the street, states "The results of our subsurface exploration and research indicate that the site was once a tidal estuary that has now been filled in and developed." It appears that Sports Center property is underlain by a variety of soil types, including loose liquefiable sand, soft clay, and a mix of soft and loose fill with some debris, based upon the results in the geotechnical engineering report. It is likely that the Depot site is underlain by similar earth materials, with a slight variation in the thickness of the sundry soil types.

The Sports Center geotechnical engineering report also states that "Significant contamination of the near-surface soils has been found and investigated during previous environmental investigations of the site. The primary constituents found in the soil are petroleum based contaminants including polynuclear aromatics." For a detailed discussion of environmental issues refer to the environmental assessment section of this report.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future.

Flooding potential due to storm-wave run-up is low to moderate. Potential impacts due to tsunamis is unknown, and will likely be difficult to ever pinpoint, due to the geologic complexity of characterizing the problem.

The Depot site is potentially underlain at shallow depths by some or all of the following: soils contaminated with hazardous substances; liquefiable sand; compressible silt, clay, and peat; non-engineered fill; and bedrock. Potential hazards due to the presence of these earth materials include liquefaction, lateral spreading, earthquake-induced settlement and static settlement. The lateral spreading hazard is dependent on the design and construction of the seawall south of the property.

Groundwater under the site will likely be shallow, salt-bearing and tidally-influenced, creating potentially corrosive foundation conditions.

Recommendations

Site-specific, detailed geotechnical engineering and engineering geology investigations should be performed to characterize the geological and geotechnical hazards and attendant risks to the proposed visitor center. A Phase II environmental investigation should be performed prior to the geotechnical engineering subsurface investigation to ascertain if the soils or groundwater on the property are contaminated. Unless determined otherwise, the subsurface and laboratory investigations should be designed assuming that hazardous substances may be present in the subsurface soil and groundwater.

The geotechnical and geologic investigations should evaluate the following hazards at a minimum:

1. Intense seismic shaking;
2. Coastal flooding due to storm-wave run-up;
3. Liquefaction and related settlement hazards;
4. The lateral spreading potential, which should include an assessment of the existing seawall;
5. Settlement due to consolidation of soft silt, clay or peat;
6. Corrosivity of the soil and groundwater;
7. Potential problems related to old non-engineered fill.

A structural investigation of the existing building and seawall should be performed following the geotechnical investigation to determine if structural modifications are needed to bring the structure and seawall in compliance with the applicable codes and engineering standards.

Potential Mitigation

It is possible that the risks associated with the aforementioned hazards may be greater than ordinary for the proposed use of the site, in the absence of any mitigation. It is important that the geologic and geotechnical engineering hazards and associated risks be adequately characterized, so the future improvements on the site may be properly designed and constructed.

The following mitigations do not address environmental contamination and may be limited by the presence of contaminated soil and groundwater.

The scope of mitigation will depend on the design and condition of the existing building (or future upgrades) and seawall, and may include: structural upgrades of the building and seawall, foundation modifications including underpinning piers, use of corrosion-resistant materials for new below-ground construction, and raising of the first floor.

Probable Range Of Costs For Detailed Geotechnical Investigation - $8,000 to $15,000
Probable Range of Costs For Detailed Geologic Investigation - $3,000 to $8,000

The above costs may be greater if the site is underlain by hazardous substances.

City Of Santa Cruz – Fun Spot

Site Conditions

The Fun Spot is a relatively flat site, located at the base of a coastal bluff, several hundred feet northwest of the shoreline. The property is roughly triangular shaped and hemmed in by the coastal bluffs, Pacific Avenue and Beach Street. A railroad cuts across the property near its' southern boundary. The site is essentially undeveloped, with the exception of temporary skateboarding structures scattered across the property.

The Fun Spot is portrayed by prior geologic researchers as being underlain by Basin Deposits and Alluvium, associated with the riverine environment of San Lorenzo River, and the lagoonal environment of Neary Lagoon. It is also implicitly underlain by Purisima Formation bedrock at depth. The aforementioned deposits are characterized as a mixed bag of sand, gravel, silt, clay and peat. In our opinion, the site may also be underlain by loose beach sand, based upon its' topographic position and past history of sea level low-stands and high-stands in the past hundred thousand years. Portions of the site may also be underlain by artificial fill, based upon past historical use.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future.

Flooding potential due to spill-over from San Lorenzo River and Neary Lagoon is high, with base flood elevations posted on the Federal Emergency Management Agency Flood Insurance Rate Map varying between 5 and 14 feet above mean sea level. Flooding potential due to storm-wave run-up may be low to moderate. Potential impacts due to tsunamis is unknown, and will likely be difficult to ever pinpoint, due to the geologic complexity of characterizing the problem.

The Fun Spot site is potentially underlain at shallow depths by some or all of the following: liquefiable sand; compressible silt, clay, and peat; non-engineered fill; and bedrock. Potential hazards due to the presence of these earth materials include liquefaction, lateral spreading, earthquake-induced settlement and static settlement. There is a high potential for significant differential settlement to occur if the site is underlain by earth materials with divergent strength characteristics. The lateral spreading hazard is dependent on the design and construction of the seawall southeast (and off) of the property.

Groundwater under the site will likely be shallow, salt-bearing and tidally-influenced, creating potentially corrosive foundation conditions.

Recommendations

Site-specific, detailed geotechnical engineering and engineering geology investigations should be performed to characterize the geological and geotechnical hazards and attendant risks to the proposed visitor center. The geotechnical and geologic investigations should evaluate the following hazards at a minimum:

1. Intense seismic shaking
2. Coastal flooding due to spill-over from Neary Lagoon and the San Lorenzo River, as well as storm-wave run-up
3. Liquefaction and related settlement hazards
4. The lateral spreading potential, which should include an assessment of the existing seawall southeast of the site.
5. Settlement due to consolidation of soft silt, clay or peat
6. Differential settlement across the site.
7. Corrosivity of the soil and groundwater
8. Potential problems related to old non-engineered fill

The depth to and configuration of the Purisima Formation bedrock under the site may be of paramount importance to any foundation design for structures on the property. It is nearly impossible at this stage to forecast or project the three-dimensional geometry of the bedrock surface under the site, in spite of the fact that the bedrock is outcropping in the coastal bluff along the margins of the property, due to the complex geologic history of the site. Any future geologic and geotechnical studies performed upon the site should focus upon characterizing the surficial deposits, as well as the configuration of the bedrock surface at depth.

A structural investigation of the existing seawall southeast of the site should be performed following the geotechnical investigation to determine if structural modifications are needed to bring the seawall in compliance with the applicable codes and engineering standards.

An engineer or surveyor experienced in flood surveys should establish the base flood elevations for the property.

Potential Mitigation

It is possible that the risks associated with the aforementioned hazards may be greater than ordinary for the proposed use of the site, in the absence of any mitigation. It is important that the geologic and geotechnical engineering hazards and associated risks be adequately characterized, so the future development on the site may be properly designed and constructed.

The scope of mitigation may depend upon the condition of the existing seawall, and may include structural upgrade of the seawall. Potential foundation mitigations for new development on the site may include: a rigid structural mat or pile foundation system, ground modifications such as vibro-replacement or geopiers, recompaction of existing fills, use of corrosion-resistant materials for new below-ground construction, and raising of the first floor.

The fact that the site may be subjected to flooding as well as liquefaction hazards may make development particularly problematic, since mitigation for those hazards can be at odds. Mitigation for flooding typically involves elevating the first floor of the structure above the base flood elevation determined for the project, while liquefaction hazards are typically mitigated by designing rigid slabs on grade or "pinning" the foundation to more stable bedrock at depth.

Probable Range Of Costs For Detailed Geotechnical Investigation - $8,000 to $15,000
Probable Range of Costs For Detailed Geologic Investigation - $3,000 to $8,000

City of Santa Cruz – Boardwalk

Site Conditions

The Beach Boardwalk site is located within an existing old (nearly one hundred years old) multi-story structure along the back edge of a coastal beach, along the border of the San Lorenzo River flood plain. Beach Hill, a bedrock "thumb" that protrudes through the surficial deposits in this area, is across the street from the structure to the northwest. The structure is elevated above the beach upon a "platform" of soil being retained by an existing seawall that fronts most of the Beach Boardwalk amusement park.

The Beach Boardwalk is portrayed by prior geologic researchers as being underlain by Basin Deposits and Alluvium associated with the riverine environment of San Lorenzo River. It is also implicitly underlain by Purisima Formation bedrock at depth. The aforementioned deposits are characterized as a mixed bag of sand, gravel silt, clay and peat, based in part upon the results of a recent geotechnical engineering study performed at the Beach Boardwalk. In our opinion, the site may also be underlain by loose beach sand, based upon its' topographic position and past history of sea level low-stands and high-stands in the past hundred thousand years. Portions of the site may also be underlain by artificial fill, based upon the results of the recent geotechnical engineering report, and past historical uses of the site.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future. The existing structure was reportedly seismically retrofitted in the mid-1980's, according to the Beach Boardwalk staff, but we have not received documentation to verify that claim. Regardless of the past retrofit, the structure may have to be investigated and seismically retrofitted to bring it in compliance with current codes and ordinances for the proposed use of a federal visitor center.

Potential impacts due to flooding are essentially nil, since the proposed Visitors Center will be located several floors above the ground surface. Potential impacts due to tsunamis is unknown, and will likely be difficult to ever pinpoint, due to the geologic complexity of characterizing the problem.

The Beach Boardwalk site is potentially underlain at shallow depths by some or all of the following: liquefiable sand; compressible silt, clay, organic-rich soil and non-engineered fill. Bedrock is about 50 feet or deeper under the existing structure, based upon the results of the recent geotechnical engineering report. Potential hazards due to these geologic conditions include liquefaction, lateral spreading, earthquake induced settlement and static settlement. The lateral spreading hazard is dependent on the design and construction of the seawall southeast of the property.

In 1906, during a large magnitude earthquake on the nearby San Andreas fault, the ground surface in the vicinity of the Beach Boardwalk was severely damaged due to intense seismic shaking, liquefaction and lateral spreading. It is unclear at this stage of our investigation if the building that was standing in the same location as the existing structure was damaged during that earthquake. The existing structure was reportedly built several months after the occurrence of the 1906 earthquake, due to a fire damaging the pre-existing building. In some sense, though, we can conclude that the existing structure has never been exposed to the intensity and duration of the seismic shaking that occurred in 1906, an event that is considered the "acid-test" for structures and seismic design in this region.

Groundwater under the site will likely be shallow, salt-bearing and tidally-influenced, creating potentially corrosive foundation conditions.

There is the potential that storm-wave erosion could impact the existing structure, depending upon the design of the existing seawall.

Recommendations

Site-specific, detailed geotechnical engineering and engineering geology investigations should be performed to characterize the geological and geotechnical hazards and attendant risks posed to locating the proposed visitor center within the existing building. The geotechnical and geologic investigations should evaluate the following hazards at a minimum:

1. The potential for intense seismic shaking to damage the existing building; a probabilistic seismic shaking hazards assessment and spectral hazards analysis may be necessary for the existing building
2. The potential for liquefaction and related settlement hazards should be characterized; their potential impacts upon the foundation of the existing building should be evaluated
3. The potential for lateral spreading to occur, which should include an assessment of the existing seawall; the potential impacts upon the foundation of the existing building should be evaluated after this hazard has been characterized
4. Settlement due to consolidation of soft silt, clay or peat; the new loading conditions that may be imposed by adding the visitor center facilities to the existing building should be evaluated; it is possible that the structure has been subjected to heavier loading in the past, depending upon types

of historical uses for the building, so we recommend that the project engineers attempt to review old records which might summarize past historical uses on the site.

5. Differential settlement across the site.
6. Corrosivity of the soil and groundwater
7. Potential problems related to old non-engineered fill

A structural investigation of the existing seawall fronting the existing building along the beach might need to be performed following the geotechnical investigation to determine if structural modifications are needed to bring the seawall in compliance with the applicable codes and engineering standards.

The project geotechnical engineer and engineering geologist should work closely with a structural engineer qualified to evaluate structural seismic shaking hazards to ascertain if the existing building is in compliance with the applicable codes and engineering standards with respect to the proposed use of the facility as a federal visitor center.

Potential Mitigation

It is possible that the risks associated with the aforementioned hazards may be greater than ordinary for the proposed use of the existing building. It is important that the geologic and geotechnical engineering hazards and associated risks be adequately characterized *with respect to the new proposed use of the building*. If the risk to the existing building is deemed to be greater than ordinary, than the identified hazards should be mitigated to lower the risk.

The scope of mitigation may depend upon the condition of the existing seawall, and may include structural upgrade of the seawall. If the risk to the existing building is deemed to be greater than ordinary, than prospective mitigation may include structural upgrades of the building, foundation modifications including underpinning piers, and the use of corrosion resistant materials for new below ground construction.

Probable Range Of Costs For Detailed Geotechnical Investigation - \$8,000 to \$10,000
Probable Range of Costs For Detailed Geologic Investigation - \$3,000 to \$8,000
Probable Range Of Costs For Geotechnical Portion Of Probabilistic Seismic Hazards Assessment And Spectral Hazards Analysis - \$4,000 to \$6,500
Probable Range Of Costs For Geologic Portion Of Probabilistic Seismic Hazards Assessment And Spectral Hazards Analysis - \$6,000 to \$7,000

County of Santa Cruz – Seacliff State Park Site

Site Conditions

The Seacliff State Beach site is located atop a relatively flat coastal bluff. The base of the bluff is protected by a retaining wall and parking area, which in turn are protected by a seawall located seaward of the bluff. An open field and parking lot occupy most of the site, with a maintenance facility occupying the extreme northwestern corner of the site.

The Seacliff State Beach site is portrayed by prior geologic researchers as being underlain by Marine Terrace Deposits associated with a past sea level high-stand. The Marine Terrace Deposits are primarily comprised of medium-dense to dense, semi-consolidated, silty and clayey sands, as noted in the exposure along the face of the bluff. Purisima Formation bedrock, comprised of siltstone and sandstone, also underlies the Marine Terrace Deposits, as noted in the bluff exposure. A layer of expansive clay may have formed within the upper five feet of the Marine Terrace Deposits, as a result of weathering over tens of thousands of years.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future.

Retreat of the coastal bluff in this area is an on-going episodic process, driven by landsliding during intense rainfall events and earthquakes, and storm-wave erosion. The sea wall located seaward of the bluff appears to have essentially eliminated the storm-wave erosion hazard, based upon our historical aerial photograph analysis. Several modes of landsliding appear to be controlling the episodic retreat of the bluff in this area. Shallow landsliding in the form of debris flows appears to episodically occur during intense periods of rainfall. Several feet of earth materials on the face of the bluff mobilizes during these events. Shallow landsliding in the form of thin (several feet thick) slabs of earth materials also appears to occur during earthquakes, such as during the 1989 Loma Prieta earthquake. Finally, there is some potential for deep-seated rotational landslides to occur during large magnitude, long duration earthquakes, such as during the 1906 earthquake.

The potential for shallow landsliding to occur within the lifetime of the proposed visitor center is high; the attendant risk is dependant upon the distance the visitor center is located from the top of the coastal bluff. The potential for deep-seated landsliding to occur with the lifetime of the proposed visitor center is moderate; as with shallow landslding, the attendant risk is dependant upon the distance with respect to top of the coastal bluff.

Recommendations

Visitor Center Set Back Greater Than 100 Feet From Top Of Bluff

For development located greater than 100 feet from the top of the bluff, we recommend that a detailed site-specific geotechnical engineering investigation be performed to characterize the stratigraphy and engineering properties of the earth materials that underlie the site. The investigation should include the following analyses:

1. Expansive potential of the foundation zone soil.
2. Settlement potential

3. Corrosivity of the soil

If the constructed facility is a one-story facility, and designed and constructed in compliance with the current California Building Code, no special seismic shaking analyses may be necessary.

Visitor Center Set Back Less Than 100 Feet From Top Of Bluff

For development located less than 100 feet from the top of the bluff, we recommend that detailed site-specific geotechnical engineering and engineering geology investigations be performed to characterize the stratigraphy and engineering properties of the earth materials that underlie the site, as well as the bluff-retreat hazards. The investigation should include the following analyses:

1. Characterization of bluff retreat hazards, including a quantitative slope stability analysis of the bluff
2. Expansive potential of the foundation zone soil
3. Settlement potential
4. Corrosivity of the soil
5. Alternative foundation and sub-grade preparation measures

If the constructed facility is a one-story facility, and designed and constructed in compliance with the current California Building Code, no special seismic shaking analyses may be necessary.

Potential Mitigation

Mitigation of the bluff erosion and landsliding hazards can easily be accomplished by setting the visitor center back from the top of the bluff. In our opinion, if the visitor center is setback 100 feet or more from the top of the bluff, geologic studies addressing the stability of the bluff will be unnecessary. Facilities located between 50 and 100 feet from the top of the bluff may have to be designed with special foundation elements to take future bluff retreat into account. Facilities located within 50 feet of the top of the bluff will likely have to be designed with special foundation elements to mitigate the impacts of future bluff retreat. Adverse effects due to the presence of expansive clay soil, if present, may be mitigated by the removal of the clay or by foundation design.

Probable Range Of Costs

Visitor Center Set Back Greater Than 100 Feet From Top Of Bluff
Probable Range Of Costs For Detailed Geotechnical Investigation - $5,000 to $10,000
No geologic investigation may be necessary.

Visitor Center Set Back Less Than 100 Feet From Top Of Bluff
Probable Range Of Costs For Detailed Geotechnical Investigation - $5,000 to $10,000
Probable Range of Costs For Detailed Geologic Investigation - $6,000 to $8,000

INTRODUCTION

This report presents the results of our geologic and geotechnical engineering feasibility investigation for four prospective sites for the proposed visitor center located in the Monterey Bay National Marine Sanctuary (MBNMS). The sites being considered are as follows:

1. The former train depot in the City of Monterey, California (Figure 1a),
2. The Fun Spot Site in the City of Santa Cruz, California (Figure 1b)
3. The Santa Cruz Beach Boardwalk site in the City of Santa Cruz, California (Figure 1c), and
4. The Seacliff Beach State Beach site in Aptos, California (in an unincorporated portion of the County of Santa Cruz; see Figure 1d).

The MBNMS staff are proposing to develop visitor center facilities in the Monterey Bay Area. We were contracted by the project planner, AMS Planning & Research, to perform a feasibility level geologic and geotechnical engineering investigation of the four above-listed prospective visitor center sites. We were also contracted to perform a feasibility level review of environmental conditions at the four sites.

The purpose of this investigation was to evaluate the geologic and geotechnical engineering feasibility of constructing a generic visitor center at the four prospective sites. We have investigated the potential geologic and geotechnical engineering hazards relevant to the proposed development. We performed the geologic analysis for this investigation, while the geotechnical engineering analysis was performed by our subcontractor, Mr. Brian Bauldry of Bauldry Engineering.

The environmental conditions review was performed by our subcontractor, Mr. Patrick Hoban of Weber, Hayes and Associates. The technical summary of their work is provided as a separate appendix under separate cover, dated 9 June 2003. Please refer to that technical summary for supportive environmental conditions details.

We were provided with the following document for this project:

"Monterey Bay National Marine Sanctuary - Visitor Center Site Feasibility Study - Phase I Draft Report" by AMS Planning & Research, dated February 2003.

SCOPE OF INVESTIGATION

Work performed during this study included:

1. Review of geologic and geotechnical literature and maps relevant to the prospective development sites, including collection and review of publically available geologic and geotechnical reports for nearby facilities, as well as examination and interpretation of historical vertical stereo pair aerial photographs.

2. Site reconnaissance and documentation of existing geologic and geotechnical conditions, including review of existing infrastructure and adjacent land use at each site.

3. Attendance at two project meetings in the project area, as well as several teleconferences.

4. Preparation of a report summarizing our findings, conclusions, and recommendations specific to the Environmental Feasibility Component of the Statement of Work, as well as the following technical summary.

No subsurface investigations were performed by our firm or our subcontractors as part of this investigation. We did not perform a detailed, site-specific, design level investigation that may be necessary to fulfill local, state and federal statutes, ordinances and codes for prospective construction of a future visitor center.

REGIONAL GEOLOGIC SETTING

The sites lie along the coastline of the Monterey Bay, at the base of the western flank of the Santa Cruz Mountains, in the central portion of the Coast Ranges physiographic province of California. This portion of the Coast Ranges is formed by a series of rugged, linear ridges and valleys following the pronounced northwest to southeast structural grain of central California geology. The Santa Cruz Mountains are mostly underlain by a large, elongate prism of granitic and metamorphic basement rocks, known collectively as the Salinian Block. These rocks are separated from contrasting basement rock types to the northeast and southwest by the San Andreas and San Gregorio-Nacimiento strike-slip fault systems, respectively. Overlying the granitic basement rocks is a sequence of dominantly marine sedimentary rocks of Paleocene (65 to 55 million years ago) to Pliocene (5.3 to 1.6 million years ago) age and non-marine sediments of Pliocene to Pleistocene (1.6 million to 11,500 years ago) age (Figure 2).

Throughout the Cenozoic Era, this portion of California has been dominated by tectonic forces associated with lateral or "transform" motion between the North American and Pacific lithospheric plates, producing long, northwest-trending faults such as the San Andreas and San Gregorio, with horizontal displacements measured in tens to hundreds of miles. Accompanying the northwest direction of the horizontal (strike-slip) movement of the plates have been episodes of compressive stress, reflected by repeated episodes of uplift, deformation, erosion and subsequent redeposition of sedimentary rocks. Near the crest of the Santa Cruz Mountains, this tectonic deformation is most evident in the sedimentary rocks older than the middle Miocene (23 to 5.3 million years ago), and consists of steeply dipping folds, overturned bedding, faulting, jointing, and fracturing. Along the coast, the ongoing tectonic activity is most evident in the formation of a series of uplifted marine terraces. The Loma Prieta earthquake of 1989 and its continuing aftershocks are the most recent reminders of the geologic unrest in the region.

In addition to tectonic effects, major changes in sea level caused by worldwide climatic fluctuations over the past million years have left their geologic imprint on the Monterey Bay region. During the last Pleistocene glacial advances between about 70,000 and 10,000 years ago, sea level stood as much as 300-400 feet below its present elevation (Helley and Lajoie, 1979). The streams presently draining into the bay likely flowed across a broad coastal plain. About 15,000 years ago, sea level began to rise as glaciers in the northern latitudes began to melt. The newly formed bay then spread rapidly inland until about 5000 to 6000 years ago when the ocean roughly reached its' present level. As sea level rose throughout this interval, the base levels of the streams in the bay region were raised slightly, and the younger alluvial sediments were deposited on the flood plains around the growing bay. In some sense, the local creeks and rivers were being drowned by the rising sea level, and so they began to backfill their channels and valleys with sediments. The coastline and its' attendant tidal marshes (at the mouths of the streams) were simultaneously migrating inland while the streams were backfilling their channels, so the end result along portions of todays' modern coastline is a complex interfingering of beach deposits, marsh and lagoon deposits and stream deposits (fluvial sediments) (Dupré; 1975, 1984, 1980, 1991).

REGIONAL SEISMIC SETTING

California's broad system of strike-slip faulting has had a long and complex history. Some of these faults present a seismic shaking hazard to the sites. The most important of these are the San Andreas, San Gregorio, Sargent, Zayante(-Vergeles), Monterey Bay-Tularcitos, Calaveras and Hayward faults (Figure 2). These faults are either active or considered potentially active (Buchanan-Banks et al., 1978; Burkland and Associates, 1975; Greene, 1977; Hall et al., 1974; Schwartz et al., 1990, and Wallace, 1990; Working Group On Northern California Earthquake Potential, 1996). Each fault is discussed below. Locations of epicenters associated with the faults are shown in Figure 3.

San Andreas Fault

The San Andreas fault is active and represents the major seismic hazard in northern California (Buchanan-Banks et al., 1978; Hall et al., 1974). The main trace of the San Andreas fault trends northwest-southeast and extends over 700 miles from the Gulf of California through the Coast Ranges to Point Arena, where the fault extends offshore.

Geologic evidence suggests that the San Andreas fault has experienced right-lateral, strike-slip movement throughout the latter portion of Cenozoic (65 million years ago to the present) time, with cumulative offset of hundreds of miles. Surface rupture during historic earthquakes, fault creep, and historic seismicity confirm that the San Andreas fault and its branches, the Hayward, Calaveras, and the San Gregorio faults, are all active today.

Historic earthquakes along the San Andreas fault and its branches have caused significant seismic shaking in the Santa Cruz County area. The two largest historic earthquakes on the San Andreas to affect the area were the moment magnitude 7.9 San Francisco earthquake of 18 April 1906 (actually centered near Olema) and the moment magnitude 7.0 Loma Prieta earthquake of 17 October 1989. The San Francisco earthquake caused severe seismic shaking and structural damage to many buildings in the Santa Cruz Mountains and the greater Monterey Bay area

(Lawson et al., 1908). The Loma Prieta earthquake appears to have caused more intense seismic shaking than the 1906 event in localized areas of the Santa Cruz Mountains, even though its regional effects were not as extensive. There were also significant earthquakes in northern California along or near the San Andreas fault in 1838, 1865 and possibly 1890 (Sykes and Nishenko, 1984; Working Group On Northern California Earthquake Potential, 1996).

Geologists have recognized that the San Andreas fault system can be divided into segments with earthquakes of different magnitudes and recurrence intervals (Working Group On California Earthquake Probabilities, 1988 and 1990). A recent study by the Working Group On Northern California Earthquake Potential (WGONCEP) in 1996 has redefined the segments and the characteristic earthquakes for the San Andreas fault system in northern and central California. Two overlapping segments of the San Andreas fault system represent the greatest potential hazard to the sites. The first segment is defined by the rupture that occurred from the Mendocino triple junction to San Juan Bautista along the San Andreas fault during the great 1906 M_w 7.9 earthquake. The WGONCEP (1996) has hypothesized that this "1906 rupture" segment experiences earthquakes with comparable magnitudes in independent cycles about two centuries long.

The second segment is defined by the rupture zone of the M_w 7.0 Loma Prieta earthquake, despite the fact that the oblique slip and depth of this event does not fit the ideal of a typical, right-lateral strike-slip event on the San Andreas fault. Although it is uncertain whether this "Santa Cruz Mountains" segment has a characteristic earthquake independent of great San Andreas fault earthquakes, the WGONCEP (1996) assumed an “idealized” earthquake of M_w 7.0 with the same right- lateral slip as the 1989 Loma Prieta earthquake, but having an independent segment recurrence interval of 138 years and a multi-segment recurrence interval of 400 years.

Sargent Fault

The Sargent fault is a zone of northwest-trending, moderate to steeply southwest dipping, thrust and right-lateral oblique-slip faults that lie northeast of the San Andreas fault. This zone of faults is roughly parallel to the San Andreas fault for 36 miles between San Juan Bautista and Lexington Reservoir, California (Figure 2). The Sargent fault appears to die out or merge with the San Andreas fault to the north. Southward, the Sargent fault extends under young alluvium and may connect with the Calaveras fault.

This fault system cuts rocks of Mesozoic to Quaternary age on the northeast side of the San Andreas. Dating of hydrothermal deposits by R.J. McLaughlin (personal communication) suggests that the Sargent fault has been active since the Miocene. Portions of the fault may have as much as 30 miles of cumulative displacement.

Evidence for late Quaternary activity on the Sargent fault is indicated by linear troughs, benches, notches, sag ponds and similar geomorphic evidence for Quaternary displacement, especially along the southern portion of the system. A study by Nolan et al. (1995) of the southern portion of the fault indicates multiple Holocene events have occurred.

Not enough is known about the paleoseismicity of the Sargent fault to reliably estimate recurrence intervals or expected earthquake magnitudes. However, the WGONCEP (1996) has modeled a hypothetical earthquake of M_w 6.8 with an effective recurrence interval of 330 years, based on a dextral surface creep rate of 3 mm/year (Prescott and Burford, 1976).

Zayante (-Vergeles) Fault

The Zayante fault lies west of the San Andreas fault and trends northwest 51 miles from the Watsonville lowlands into the Santa Cruz Mountains. The southern extension of the Zayante fault, known as the Vergeles fault, merges with the San Andreas fault south of San Juan Bautista.

The Zayante fault has a long, well-documented history of vertical movement (Clark and Reitman, 1973), probably accompanied by right-lateral, strike-slip movement (Hall et al., 1974; Ross and Brabb, 1973). Stratigraphic and geomorphic evidence indicates the Zayante fault has undergone late Pleistocene and Holocene movement and is potentially active (Buchanan-Banks et al., 1978; Coppersmith, 1979).

Some historic seismicity may be related to the Zayante fault (Griggs, 1973). For instance, the Zayante fault may have undergone sympathetic fault movement during the 1906 earthquake centered on the San Andreas fault, although this evidence is equivocal (Coppersmith, 1979). Seismic records strongly suggest that a section of the Zayante fault approximately 3 miles long underwent sympathetic movement in the 1989 earthquake. The earthquake hypocenters tentatively correlated to the Zayante fault occurred at a depth of 5 miles; no instances of surface rupture on the fault have been reported.

In summary, the Zayante fault should be considered potentially active. The WGONCEP (1996) considers it capable of generating a magnitude 6.8 earthquake with an effective recurrence interval of 10,000 years.

Calaveras Fault

The nearest Calaveras fault segment to the sites is the Southern Calaveras fault (after WGONCEP, 1996). The "Morgan Hill" earthquake of April 24, 1984 ($M_W = 6.2$) occurred on the Southern Calaveras Fault in the Halls Valley area about 30 miles northwest of the site (Hoose, 1987). The "Coyote Lake" earthquake of August 6, 1979 ($M_s = 5.9$) also occurred on the Calaveras fault, about 15 miles north of the site. No damage was reported on the sites from either earthquake, but regionally, several million dollars worth of damage occurred, and several people were injured in each earthquake.

In 1897, an earthquake with an approximate Richter magnitude (M_s) of 6 occurred along the southern portion of the Calaveras Fault, somewhere near the epicenter of the 1979 event, while an earthquake of magnitude 6.6 occurred on the fault in 1911 fairly close to the epicenter of the 1984 event.

The WGONCEP (1996) suggested using the 1984 Morgan Hill M_W 6.2 earthquake as a maximum magnitude event with an effective recurrence interval of 60 years along the entire length of the Southern Calaveras fault.

Hayward Fault

The Hayward fault zone, located on the eastern side of the San Francisco Bay, is a 2 to 10 kilometer wide zone of deformed rocks resulting from tectonic "transpression" for the last 10 million years (Graymer et al., 1995). The active trace of the Hayward fault lies in the western portion of this complex fault zone and exhibits evidence of both surface rupture and aseismic creep, creating the prominent geomorphic expression exhibited along the length of the fault.

The active fault is divided into two segments, each 43 kilometers: a northern segment extending from San Pablo Bay to San Leandro and a southern segment extending from San Leandro southward to east of San Jose (WGNCEP, 1996; Petersen et al., 1996). The boundaries of the segments are defined by geomorphic expression and creep rates (WGNCEP, 1996).

The last damaging earthquake on the fault was the magnitude 7, 1868 earthquake on the southern segment, rupturing the ground surface for 30 kilometers from Warm Springs to San Leandro, and possibly to Mills College in Oakland (Lawson et al., 1908). Lienkaemper and Williams (1999) suggest that surface rupture in 1868 extended northward to at least Oakland, based on their recent paleoearthquake investigation in Montclair Park, while Yu and Seagal (1996) postulated that the 1868 rupture extended as far north as Berkeley, based on their new analysis of triangulation data collected before and after the 1868 earthquake.

The northern segment of the Hayward fault was estimated by the WGCEP (1990) to have the highest probability (28 percent) of producing a magnitude 7 earthquake by the year 2020. This hazard assessment was based on the incorrect assumption that the last large earthquake on the northern segment of the fault occurred in 1836 (Louderback, 1947). This assumption was later refuted by Toppozada and Borchardt (1998) after they researched and analyzed the primary historical archives and demonstrated the 1836 earthquake did not occur on the Hayward fault but occurred south of the Bay Area. The most recent earthquake on the northern Hayward fault occurred sometime before 1776 (the founding date of Mission San Francisco Dolores, and therefore, the first available written records).

The WGNCEP (1996) subdivision of the fault is hypothetical; the "actual" segmentation and recurrence history of the Hayward fault remains a mystery. They have assigned a coseismic slip of 1.9 meters and a 12 kilometer rupture depth (after Oppenheimer et al., 1992), producing a M_w 6.9 for each segment. The expected rupture event on the assumed segments yields a recurrence interval of 210 years, using the regional slip rates and applying the method of Savage and Lisowski (1993). This recurrence interval closely agrees with the best estimate of recurrence advanced by Williams (1993) for the southern Hayward fault based on his paleoearthquake investigation at Tule Pond in Fremont.

Petersen et al. (1996) chose to retain the 1.5 meter coseismic slip and 167 year recurrence interval adopted by WGCEP (1990) for two Hayward fault segments, which similarly yields a M_w 6.9 and identical rate of moment release. Although their assumed coseismic slip for both segments is smaller than that advanced by the WGNCEP (1996), it is a more cautious assumption for probabilistic seismic hazards assessments given the great uncertainty in recurrence intervals for large magnitude earthquakes along the Hayward fault.

Petersen et al. (1996) and the WGCEP (1996) also broke out an ill-defined, 26-kilometer continuation of the Hayward fault, the so-called "Southeastern Extension of the Hayward fault." It appears that the geologic parameters for this fault segment, particularly the unconstrained slip rate of 2 millimeters per year, were assigned as way of balancing the slip budget between the Calaveras and the Hayward faults. Admittedly, neither of these research groups considered a possible reverse component along this short fault segment.

San Gregorio Fault

The San Gregorio fault, as mapped by Greene (1977), Weber and Lajoie (1974), and Weber et al. (1995) skirts the coastline of Santa Cruz County northward from Monterey Bay, and trends onshore at Point Año Nuevo. Northward from Año Nuevo, it passes offshore again, to connect with the San Andreas fault near Bolinas. Southward from Monterey Bay, it may trend onshore north of Big Sur (Greene, 1977), to connect with the Palo Colorado fault, or continue southward through Point Sur to connect with the Hosgri fault in south-central California. Based on these two proposed correlations, the San Gregorio fault zone has a length of at least 100 miles, and possibly as much as 250 miles.

The landward extension of the San Gregorio fault at Point Año Nuevo shows evidence of late Pleistocene (Jennings, 1975; and Buchanan-Banks et al., 1978) and Holocene displacement (Weber and Cotton, 1981). Although stratigraphic offsets indicate a history of horizontal and vertical displacements, the San Gregorio is considered predominantly right-lateral strike slip by most researchers (Greene, 1977; Weber and Lajoie, 1974; and Graham and Dickinson, 1978).

In addition to stratigraphic evidence for Holocene activity, the historical seismicity in the region is partially attributed to the San Gregorio fault (Greene, 1977). Due to inaccuracies of epicenter locations, even the magnitude 6+ earthquakes of 1926, tentatively assigned to the Monterey Bay fault zone, may have actually occurred on the San Gregorio fault (Greene, 1977).

The WGONCEP (1996) has divided the San Gregorio fault into the "San Gregorio" and "San Gregorio, Sur Region" segments. The segmentation boundary is located west of the Monterey Bay, where the fault appears to have a right step-over. The San Gregorio fault has been assigned a slip rate that results in a M_w 7.3 earthquake with a recurrence interval of 400 years. This is based on the preliminary results of a paleoseismic investigation at Seal Cove by Lettis and Associates (see WGONCEP, 1996), and on regional mapping by Weber et al. (1995). The Sur Region segment has been assigned a slip rate that results in a M_w 7.0 earthquake with an effective recurrence interval of 400 years (coincidental with respect to the recurrence interval for the other segment). The Sur Region earthquake was derived from an assumed slip rate similar to that of the Hosgri fault.

Monterey Bay-Tularcitos Fault Zone

The Monterey Bay-Tularcitos fault zone is 6 to 9 miles wide, about 25 miles long, and consists of many en échelon faults identified during shipboard seismic reflection surveys (Greene, 1977). The fault zone trends northwest-southeast and intersects the coast in the vicinity of Seaside and Ford Ord. At this point, several onshore fault traces have been tentatively correlated with offshore traces in the heart of the Monterey Bay-Tularcitos fault zone (Greene, 1977; Clark et al., 1974; Burkland and Associates, 1975). These onshore faults are, from southwest to northeast, the Tularcitos-Navy, Berwick Canyon, Chupines, Seaside, and Ord Terrace faults. Only the larger of these faults, the Tularcitos-Navy and Chupines, are shown on Figure 2. It must be emphasized that these correlations between onshore and offshore portions of the Monterey Bay-Tularcitos fault zone are only tentative; for example, no concrete geologic evidence for connecting the Navy and Tularcitos faults under the Carmel Valley alluvium has been observed, nor has a direct connection between these two faults and any offshore trace been found.

Outcrop evidence indicates a variety of strike-slip and dip-slip movement associated with onshore and offshore traces. Earthquake studies suggest the Monterey Bay-Tularcitos fault zone is predominantly right-lateral, strike-slip in character (Greene, 1977). Stratigraphically, both offshore and onshore fault traces in this zone have displaced Quaternary beds and, therefore, are considered potentially active (Buchanan-Banks et al., 1978). One offshore trace, which aligns with the trend of the Navy fault, has displaced Holocene beds and is therefore active by definition (Buchanan-Banks et al., 1978).

Seismically, the Monterey Bay-Tularcitos fault zone may be historically active. The largest historical earthquakes *tentatively* located in the Monterey Bay-Tularcitos fault zone are two events, estimated at 6.2 on the Richter Scale, in October 1926 (Greene, 1977). Because of possible inaccuracies in locating the epicenters of these earthquakes, it is possible that they actually occurred on the nearby San Gregorio fault zone (Greene, 1977).

Another earthquake in April 1890 might be attributed to the Monterey Bay-Tularcitos fault zone (Burkland and Associates, 1975); this earthquake had an estimated Modified Mercalli Intensity of VII (Table 1) for Monterey County on a whole.

The WGONCEP (1996) has assigned an earthquake of M_w 7.1 with an effective recurrence interval of 2,600 years to the Monterey Bay-Tularcitos fault zone, based on Holocene offshore offsets. Petersen et al. (1996) have a similar earthquake magnitude, but for a recurrence interval of 2,841 years. Their earthquake is based on a composite slip rate of 0.5 millimeters per year (after Rosenberg and Clark, 1995).

The WGONCEP (1996) has assigned an earthquake of M_w 7.1 with an effective recurrence interval of 2600 years to the Monterey Bay-Tularcitos fault zone, based on Holocene offshore offsets. Petersen et al. has a similar earthquake magnitude, but for a recurrence interval of 2841 years. Their earthquake is based on a composite slip rate of 0.5 millimeters per year (after Rosenberg and Clark, 1995).

TABLE 1
Modified Mercalli Intensity Scale

The modified Mercalli scale measures the intensity of ground shaking as determined from observations of an earthquake's effect on people, structures, and the Earth's surface. Richter magnitude is not reflected. This scale assigns to an earthquake event a Roman numeral from I to XII as follows:

I	Not felt by people, except rarely under especially favorable circumstances.
II	Felt indoors only by persons at rest, especially on upper floors. Some hanging objects may swing.
III	Felt indoors by several. Hanging objects may swing slightly. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Felt indoors by many, outdoors by few. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing automobiles rock. Windows, dishes, doors rattle. Wooden walls and frame may creak.
V	Felt indoors and outdoors by nearly everyone; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset; some dishes and glassware broken. Doors swing; shutters, pictures move. Pendulum clocks stop, start, change rate. Swaying of tall trees and poles sometimes noticed.
VI	Felt by all. Damage slight. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks and books fall off shelves; pictures off walls. Furniture moved or overturned. Weak plaster and masonry cracked.
VII	Difficult to stand. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in badly designed or poorly built buildings. Noticed by drivers of automobiles. Hanging objects quiver. Furniture broken. Weak chimneys broken. Damage to masonry; fall of plaster, loose bricks, stones, tiles, and unbraced parapets. Small slides and caving in along sand or gravel banks. Large bells ring.
VIII	People frightened. Damage slight in specially designed structures; considerable in ordinary substantial buildings, partial collapse; great in poorly built structures. Steering of automobiles affected. Damage or partial collapse to some masonry and stucco. Failure of some chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed pilings broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Damage considerable in specially designed structures; great in substantial buildings, with some collapse. General damage to foundations; frame structures, if not bolted, shifted off foundations and thrown out of plumb. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground; liquefaction.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Landslides on river banks and steep slopes considerable. Water splashed onto banks of canals, rivers, lakes. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Few, if any masonry structures remain standing. Bridges destroyed. Broad fissures in ground; earth slumps and landslides widespread. Underground pipelines completely out of service. Rails bent greatly.
XII	Damage nearly total. Waves seen on ground surfaces. Large rock masses displaced. Lines of sight and level distorted. Objects thrown upward into the air.

POTENTIAL GEOLOGIC AND GEOTECHNICAL IMPACTS

The following sub-headings for this section are intended to give an explanation and overview of the hazards studied at the four sites. Certain hazards are addressed more specifically in a following site section.

Seismic Shaking

Strong ground shaking may occur on the sites during a major earthquake on a regional fault system. Such shaking can cause severe damage to or collapse of buildings or other project facilities and may result in significant economic loss to the project and/or endanger the health and welfare of persons using the facility, a potentially significant impact.

Without mitigation, strong seismic shaking in the project vicinity would produce serious damaging effects in the planning area. Many buildings in the area, especially those on Monterey Train Depot and Santa Cruz Beach Boardwalk sites, were built before modern seismic safety provisions were incorporated into the California building codes, and therefore may not comply with current building codes for a federal visitor center.

The effects of ground shaking on <u>future</u> planned structures and other improvements can be reduced by earthquake-resistant design in accordance with the latest editions of the Uniform Building Code and the California Building Code. The potential effects of ground shaking on <u>existing</u> structures can be evaluated by engineering studies. Where studies indicate that buildings may be subject to significant damage during earthquakes, the structures can be retrofitted for seismic resistance.

It is important that recommendations regarding seismic shaking be used in the design for any proposed development. Even with adequate design and construction, some damage to structures may occur during a great earthquake. However, the damage due to high intensity shaking may be reduced by careful placement and construction of the structure. Past experience has shown that the quality of design and construction is far more important than the precise evaluation of ground motion parameters.

Many of the risks associated with earthquakes are not due to structural failure. Most injuries result from falling debris, overturned furniture, the disruption of utilities, and fires that occur as a result of broken utility lines, overturned gas stoves, etc. Large appliances (i.e. refrigerators, freezers, pianos, wall units, water heaters, etc.) should be firmly attached to the floor or to structural members of walls.

There are two commonly used methods for estimating seismic ground motions for a given area: “deterministic” and “probabilistic”. A deterministic approach estimates the magnitude of the most severe shaking that can be expected at a particular site, without regard for how likely such shaking is to occur. A probabilistic analysis evaluates a range of ground motions, and specifies a probability for each level of shaking intensity. The probabilistic evaluation allows one to select a specified risk level for design which may be adequate for the structure, without having to design for a more severe, but less likely shaking intensity. While a probabilistic analysis represents a more sophisticated approach to seismic design, both approaches yield important information for evaluating risks due to seismic shaking.

Even after detailed seismic studies are completed, the values derived from such studies can only be regarded as average ground motion values. Actual ground motions during an earthquake may vary due to differences in the way portions of the earths crust transmit seismic energy or because of unique site conditions, such as bedrock type or topography. Sites on thick fluvial deposits may experience stronger shaking due to the tendency of soft, unconsolidated deposits to amplify ground motions that affect buildings. Variation in seismic hazards will reflect the relative hazard posed by different types of earth materials, including their propensity for seismic shaking induced ground failures such as liquefaction, lateral spreading, or landsliding.

Seismically-Induced Ground Deformation

Ground deformation associated with strong seismic shaking may manifest in several ways:

Differential settlement occurs where the seismic shaking compacts loose soils, causing them to settle. Since the condition of soils is generally not uniform, the settlement is typically uneven. Such settlement can throw buildings out of level and damage foundations.

Seismically induced landsliding takes place where slopes that are already marginally stable move as a result of the added stress caused by seismic shaking.

Liquefaction occurs when generally loose, saturated, cohesionless soils (typically sands) compact under the effects of seismic shaking. As the sand compacts, the weight of the overlying soil is temporarily supported by water trapped in the diminishing pore spaces and the soil loses shear strength, causing it to behave like a liquid. Ground deformation that accompanies liquefaction includes lurch cracking, fissuring, differential settlement, and sand volcanoes.

Lateral spreading takes place where an area of liquefied soil is bounded on one side by bluff or steep slope, permitting the soil column to flow some distance out of the slope. Lateral spreading occurs most commonly along river banks, where loose, freshly deposited flood plain sediments liquefy and flow towards the river.

The first three types of ground failure listed above can occur with or without the presence of water. Differential settlement may occur anywhere that soils are in a loose state. This hazard, however, can generally be easily mitigated by appropriate foundation design. A further discussion of liquefaction and lateral spreading is in the following section.

Liquefaction and Lateral Spreading Hazards

The physical process of seismically induced liquefaction has been documented by numerous researchers (Youd, 1973; Seed and Idriss, 1982; National Research Council, 1985). During an earthquake seismic waves travel through the earth and vibrate the ground. In cohesionless, granular materials having low relative density (loose sands for example), this vibration can disturb the particle framework, thus leading to increased compaction of the material and reduction of pore space between the framework grains. If the sediment is saturated, water occupying the pore spaces resists this compaction and exerts pore pressure that reduces the contact stress between the sediment grains. With continued shaking, transfer of intergranular stress to pore water can generate pore pressures great enough to cause the sediment to lose its strength and change from a solid state to a liquefied state. This mechanical transformation can cause various kinds of ground failure at or near the ground surface.

The liquefaction process typically occurs at depths less than 50 feet below the ground surface. Liquefaction can occur at deeper intervals, given the right conditions, however ground manifestations should be minor. The most susceptible zone occurs at depths shallower than 30 feet below the ground surface. Diminished susceptibility with increase in depth can be attributed mainly to two factors: 1) increased overburden pressure resulting from the load of overlying sediment layers, and 2) increased geologic age. These two factors tend to create a denser packing of sediment grains in the deeper sedimentary materials, which thus are less likely to experience the additional compaction and elevated pore pressures that are necessary to induce loss of shear strength and liquefaction during an earthquake.

Liquefaction can lead to several types of ground failure, depending on slope conditions and the geologic and hydrologic setting (Seed, 1968; Youd, 1973; Tinsley et al, 1985). The four most common types of ground failure are: 1) lateral spreads, 2) flow failures, 3) ground oscillation and 4) loss of bearing strength. Sand boils (injections of fluidized sediment) commonly accompany these different types of ground failure and form sand volcanoes at the ground surface or convolute layering and sand dikes in subsurface sediment layers.

Detailed studies of different earthquakes and associated liquefaction events (Lawson, 1908; Youd and Hoose, 1978; Tinsley and Dupré, 1992; Obermeier, 1989; Ziony, 1985; Youd and Wieczorek, 1982; Muir and Scott, 1982) has shown the following:

1. Lateral spreading is generally limited to unconsolidated late Holocene fluvial, basin, estuarine, channel-fill and beach deposits. The toes of the lateral spreads are typically located in the faces of active channel margins or shorelines. The heads of lateral spreads are typically located between the contact of young channel deposits with either overbank deposits of equivalent age, or overbank deposits of older Holocene units. Lateral spread fissures tend to follow the flow directions of the fluvial deposits.

2. Lateral spread fissures have occurred as far as 7 miles away from the main channel of a river in fluvial environments (Obermeier, 1989), and have been mapped up to 0.5 miles in length. The lateral spreads appear to occur most commonly on slopes with gradients of 0.3 to 3 degrees. During the 1989 Loma Prieta earthquake, lateral spread failures occurred as far as 150 meters from the active stream channel of the Pajaro River in the nearby cities of Watsonville and Pajaro. The 1989 Loma Prieta earthquake induced failures had lateral

displacements of a few millimeters to 2 meters and vertical displacements that were typically less than 30 centimeters.

The different types of ground failure associated with liquefaction often leave geomorphic evidence after the event in the form of scarps, and open (or infilled) ground cracks, and sand volcanoes. This type of evidence can be readily observed via site reconnaissance or aerial photo analysis on undisturbed ground long after the liquefaction has occurred. However, if the ground surface is disturbed, such as by subsequent activities of man, the ground information is erased. We did not observe evidence of differential settlement, lurch cracking or lateral spreading during our aerial photo analysis or our reconnaissance to the various sites. However, any evidence of past liquefaction may have been obscured by cultural activities in these areas.

Landsliding

In general, slope stability hazards at all the sites except for the Seacliff Beach State Park site are low, owing to the relatively gentle topography throughout those areas. The steep coastal bluff at the Seacliff Beach State Park, however, may be susceptible to elevated slope stability hazards. Development on or in close proximity to the bluff must consider the potential for landsliding under ordinary conditions or as a result of strong earthquakes.

Erosion

Erosion may take place due to water runoff from precipitation or wave attack.

Problems with erosion typically arise when development disrupts native soil conditions. Common impacts of development such as the removal of vegetative cover, reduction of permeable area, and steepening of slopes all lead to increased runoff rates and concentrated flows which can quickly erode unconsolidated soils.

Coastal erosion within the Monterey Bay area is a long-term natural process that has been occurring for at least the last several thousand years. Changes in the coastline configuration, post-glacial sea level rise and episodic storm wave action are several factors that have produced the rapid erosion of the coastline. Dam and jetty construction within the local river systems and ocean have also been major contributors in accelerating the rate of erosion as a result of decreasing the sediment flux along the coast, essentially starving beaches of their annual sand supply. Coastal bluff retreat rates performed for site specific design studies are typically only reported as historic averages. However, it is important to note that the "average retreat rate" actually takes place as infrequent, large erosional events. The retreat rate can also vary depending on long term trends in climate, particularly those responsible for a rise in sea level. The sea level rise predicted for the next century due to global warming may increase the rate of coastal erosion.

Tsunami Hazard

Tsunamis are produced when movement occurs on faults in the ocean floor, usually during very large earthquakes. Sudden vertical movement of the ocean floor by fault movement displaces the overlying water column, creating a wave that travels outward from the earthquake source. An earthquake anywhere in the Pacific can cause tsunamis around the entire Pacific basin. Since the Pacific Rim is highly seismically active, tsunamis are not uncommon.

Historically, this portion of the California coast has not been subject to significant tsunami hazard. Of the 19 tsunami events recorded at the mouth of San Francisco Bay since 1868, none have exceeded 3.9 feet (1.2 meters) in height (Griggs and Gilchrist, 1983). The tsunami from the 1964 Alaskan earthquake was 9.8 feet (3 meters) high at Half Moon Bay, 40 miles south of San Francisco (Shepard, 1963). Table 2 lists tsunami heights recorded around Monterey Bay as a result of the three major earthquakes around the Pacific Ocean in the last 50 years. Maximum tsunami wave heights reached nine feet (2.7 meters) at Monterey harbor due to the 1964 Alaskan earthquake (Table 2).

The US Army Corps of Engineers has looked at potential earthquake sources around the Pacific and modeled expected tsunami impacts on the coast of the Monterey Bay (US Army Corps of Engineers, 1975). Their study estimated that a tsunami wave with a probability of occurrence of one every 100 years would be about 5.9 feet high. A tsunami with a probability of occurrence of one every 500 years is expected to be 11.5 feet high.

We hasten to add, however, that we have fairly low confidence in the past modeling of tsunamis for the Monterey Bay region. The physical process of tsunami wave run up is poorly understood, as is the recurrence intervals of *all* the seismogenic sources around the entire Pacific Rim. To perform a statistically robust analysis of the fault systems as well as the topography of the floor of near shore areas would be monumental and has thus far eluded researchers. Perhaps such a study may occur in the future, but for now, the hazard will essentially remain uncharacterized along coastal California.

TABLE 2: Summary of Tsunamis in Monterey County

Source Earthquake	Measurement Location	Comments
April 1, 1946 Aleutian Islands Earthquake	Pacific Grove	height uncertain
	Monterey Harbor	no effects or damages noted
	Moss Landing	no effects or damages noted
May 22, 1960 Chilean Earthquake	Pacific Grove	6 ft. wave height
	Monterey Harbor	5 ft. wave height
	Moss Landing	5 ft. wave height
March 28, 1964 Gulf of Alaska Earthquake	Pacific Grove	6 ft. wave height
	Monterey Harbor	9 ft wave height, damage estimated at $1,000
	Moss Landing	9 ft. maximum wave height

Table from Burkland and Associates, 1975.

Flooding

Two of the sites may be at risk from inundation by ocean storm waves and flooding rivers, based on the relatively low topographic position of the of the properties and portrayal by regional flooding maps provided the Federal Emergency Management Agency. The primary flooding hazard is due to ocean storm waves. The following sub-section describe the storm history of the Monterey Bay.

Storm History of Monterey Bay, 1910-1983

Review of the storm history of Monterey Bay leads us to several immediate conclusions:

1) The number of large storms affecting Monterey Bay is relatively large.

2) The storms which produced the greatest damage in the interior of the Bay often came from the west or southwest.

3) Structures directly exposed to wave action, or designed to protect ocean front properties from such action, have been regularly damaged or destroyed.

For the period of most detailed record, 1910-1960, there have been at least 45 storms of some significance (i.e., either high seas, strong winds, and/or damage to at least some portion of the Monterey Bay region). Thus, considering the 50 years of detailed records, this amounts to a major storm every 1.1 years on the average. Analysis of the record reveals that no major storms were recorded for some intervals as long as seven years (1916-1923), but in other cases, five significant storms occurred within a single year (1931). If we consider the entire period, 1910-1983, we have a major storm every 1.5 years on the average.

This historical record indicates that the northern one-half of Monterey Bay (Moss Landing to Santa Cruz) is most susceptible to damage from storms arriving from the west or southwest (Griggs and Johnson, 1983; Johnson and Associates, 1987). Waves from the northwest, which predominate along the central coast, undergo refraction or bending, which results in a significant energy loss prior to striking beaches along the interior of the Bay. Thus, although waves from the WNW and NW dominate along the coastline, their effect on the interior of the Bay appears to have been relatively small. In contrast, the storm waves approaching from the W, WSW and SW pass primarily over the deep water on their way to the shoreline within the Bay and lose little energy. These storms have produced the greatest recorded damage at the north end of the Bay.

Of the 45 major storms in the study period, 1910-1960, 20 have been listed as coming from the southwest or west; only 12 are described as arriving from the north or northwest (the remainder list no direction of approach). Of the 13 storms which have produced significant damage along the Bay's interior, only one is described as coming from the northwest; 11 arrived from the southwest, and for two of these, the direction was not listed. Thus, at least 85 percent of the storms which have caused damage approached from the south or southwest. Looking at the frequency of arrival of these storms, 13 have occurred in 69 years. In other words, damaging storms will strike the area every 5.3 years on the average. This does not mean that storms will actually occur every 5.3 years, of course.

The record of historical storm damage illuminates some other processes of relevance to the study area. The past damage to the Monterey Bay coastal area was often caused by the coupling or simultaneous occurrence of high tide and huge waves.

Deep-Water Wave Conditions

Wave data has been compiled from three different sources of numerous deep-water stations and also visual observations off Central California.

1) Ships' sea and swell reports summarized by the National Climatic Center and published by the U.S. Naval Weather Service Command as "Summary of Synoptic Meteorological Observation (SSMO)--North American Coastal Marine Areas--Pacific Coast".

2) "Wave Statistics for Seven Deep Water Stations along the California Coast", published by National Marine Consultants (1960).

3) "Deep-Water Wave Statistics for the California Coast", published by Meteorology International Incorporated (1977), based on hindcasts by the U.S. Fleet Numerical Weather Central.

As mentioned in the previous discussion of storms, the great majority of waves arrive from the northwest, but these must undergo significant energy loss through diffraction. Thus, waves from the southwest are normally of greater concern. Using hindcasting data from a station offshore from San Francisco (Nat. Mar. Cons., 1960), we can expect waves in excess of nine feet in height, on the average, 23 days of each year, and waves in excess of 15 feet three days each year. The storm record discussed earlier indicates storm waves ranging in height from 20 to 25 feet, arriving from the southwest, were recorded in 1939, 1940 and 1941. This data indicates that waves in excess of 10 to 15 feet are common in an average year, and waves in excess of 20 feet occur as well, although less frequently.

The potential impact of such storm waves on any given site can be quantified by wave runup analysis, as discussed in the next section.

Wave Runup Analysis

Coastal flood hazards can be quantified to some degree by using wave runup analysis. This procedure is site specific, taking into account past storm frequencies, wave characteristics, bathymetry, and beach profile, as well as antecedent astronomical and meteorological conditions. Wave runup analysis can be explained in a qualitative way by reference to the generalized sketch. The first step is to establish the expected "stillwater" elevation, representing the static water surface upon which the waves will be superimposed. Note that the stillwater elevation is higher than mean sea level for a number of reasons. The normal tidal range must be taken into account, obviously, because shoreline damage will be most severe during high tide. However, there are additional, less intuitive factors that tend to raise the stillwater elevation. Abnormally low barometric pressure and persistent onshore winds during storms, for instance, will both push up the water surface to some degree.

Stillwater elevations are expressed in probabilistic terms, much like storm frequencies. For design purposes, the Federal Emergency Management Agency (FEMA) and other governmental agencies have typically adopted the "100-year" conditions as a basis for their runup analyses. In this time frame, the slow but general rise of sea level must also be accommodated in the analysis (e.g., see Environmental Protection Agency, 1983; Hoffman, 1984).

With the stillwater elevation established, the next step is to superimpose the effects of storm waves on the shoreline, using computer models. These models typically use historical data for deep-water wave conditions and direction of approach combined with field data for bathymetry and beach profiles. Again, the results are expressed in probabilistic terms with the 100-year event as the benchmark. Typically, the project geologist and geotechnical engineer complete detailed wave runup analyses for the beach adjacent to any property being considered for development along the shoreline, incorporating the shoreline configuration depicted on site-specific geologic cross sections.

Soils With Geotechnical Engineering Constraints

The soils underlying the sundry sites have limitations as substrates for engineering and construction purposes. These limitations are related to certain soil properties that result in low soil strength or shrink-swell potential.

Soils with shrink-swell potential (called *expansive soils*) have clay minerals which expand when wet and shrink when dried. Shrink-swell can cause seasonal uplifting of foundations and roads that results in cracking

The impact of potentially weak soils on development is generally manifested in two primary ways, as problems associated with low shear strength, affecting primary bearing capacity and slope stability, and as problems associated with loss of strength due to cyclic loading during seismic activity, affecting the potential for liquefaction, lateral spreading and seismically induced differential settlements (see above sections).

Low strength soils lack the cohesive bond supplied by organic or clay materials that enable a soil to support itself when burdened by extra weight such as added water or overlying development. When a load is added to a low strength soil, the additional weight may exceed the cohesive bonds that exist between the soil particles. For this reason, soils with low strengths may fail when improperly loaded.

INDIVIDUAL SITES

City of Monterey - Monterey Historic Train Depot

Site Conditions

The Monterey Historic Train Depot is a relatively flat site set amidst a set of train tracks, slightly south of the Monterey Bay coastline. The Depot building is surrounded by large parking lots. A seawall, located north of the Depot property, protects developments in this area from erosion and coastal flooding due to storm-waves.

The Depot site is mapped as being underlain by artificial fill inset into the Ocean View Coastal Terrace by Clark and Rosenberg (1997) (see Figure 4). A prior geotechnical engineering report, prepared for the Monterey Sports Center (by Terratech, 1990), located south of the site, across the street, states:

> *"The results of our subsurface exploration and research indicate that the site was once a tidal estuary that has now been filled in and developed."*

It appears that Sports Center property is underlain by a variety of soil types, including loose liquefiable sand (Terratech, 1990), soft clay, and a mix of soft and loose fill with some debris. Depth to Monterey Formation and granodiorite bedrock on the Sports Center property is highly variable and ranges between 25 and 35 feet across the site. The surficial materials overlie the bedrock unconformably, which is consistent with the highly variable nature of the buried bedrock surface.

It is likely that the Depot site is underlain by similar earth materials, with a slight variation in the thickness of the sundry soil types.

The Sports Center geotechnical engineering report also states that:

"Significant contamination of the near-surface soils has been found and investigated during previous environmental investigations of the site. The primary constituents found in the soil are petroleum based contaminants including polynuclear aromatics."
For a detailed discussion of environmental issues refer to the summary of environmental conditions for this site in the separate technical appendix prepared by Weber, Hayes and Associates.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future.

Flooding potential due to storm-wave run-up is low to moderate (Figure 5). Potential impacts due to tsunamis is unknown, and will likely be difficult to ever pinpoint, due to the geologic complexity of characterizing the problem.

The Depot site is potentially underlain at shallow depths by some or all of the following: soils contaminated with hazardous substances; liquefiable sand (Figure 6); compressible silt, clay, and peat; non-engineered fill; and bedrock. Potential hazards due to the presence of these earth materials include liquefaction, lateral spreading, earthquake-induced settlement and static settlement.

The lateral spreading hazard is dependent on the design and construction of the seawall south of the property. In the event that the seawall is inadequately designed, it may fail during a nearby large magnitude earthquake, allowing the potentially liquefiable soils it is currently retaining to laterally spread toward the bay and the ensuing free face.

Groundwater under the site will likely be shallow, salt-bearing and tidally-influenced, creating potentially corrosive foundation conditions.

Recommendations

Site-specific, detailed geotechnical engineering and engineering geology investigations should be performed to characterize the geological and geotechnical hazards and attendant risks to the proposed visitor center. A Phase II environmental investigation (involving environmental sampling and lab analysis of soils) should be performed prior to the geotechnical engineering subsurface investigation to ascertain if the soils or groundwater on the property are contaminated. Unless determined otherwise, the subsurface and laboratory investigations should be designed assuming that hazardous substances may be present in the subsurface soil and groundwater.

The geotechnical and geologic investigations should evaluate the following hazards at a minimum:

1. Intense seismic shaking;
2. Coastal flooding due to storm-wave run-up;
3. Liquefaction and related settlement hazards;
4. The lateral spreading potential, which should include an assessment of the existing seawall;
5. Settlement due to consolidation of soft silt, clay or peat;
6. Corrosivity of the soil and groundwater;
7. Potential problems related to old non-engineered fill.

A structural investigation of the existing building and seawall should be performed following the geotechnical investigation to determine if structural modifications are needed to bring the structure and seawall in compliance with the applicable codes and engineering standards.

Potential Mitigation

It is possible that the risks associated with the aforementioned hazards may be greater than ordinary for the proposed use of the site, in the absence of any mitigation. It is important that the geologic and geotechnical engineering hazards and associated risks be adequately characterized, so the future improvements on the site may be properly designed and constructed.

The following mitigations do not address environmental contamination and may be limited by the presence of contaminated soil and groundwater.

The scope of mitigation will depend on the design and condition of the existing building (or future upgrades) and seawall, and may include: structural upgrades of the building and seawall, foundation modifications including underpinning piers, use of corrosion-resistant materials for new below-ground construction, and raising of the first floor.

If any prospective risks are deemed to be greater than *ordinary*, as defined in Appendix A of this technical summary, they should be mitigated to lower the risk to an ordinary level.

Probable Range Of Costs For Detailed Geotechnical Investigation - $8,000 to $15,000
Probable Range of Costs For Detailed Geologic Investigation - $3,000 to $8,000

The above costs may be greater if the site is underlain by hazardous substances.

City Of Santa Cruz – Fun Spot

Site Conditions

The Fun Spot is a relatively flat site, located at the base of a coastal bluff, several hundred feet northwest of the shoreline. The property is roughly triangular shaped and hemmed in by the coastal bluffs, Pacific Avenue and Beach Street. A railroad cuts across the property near its' southern boundary. The site is essentially undeveloped, with the exception of temporary skateboarding structures scattered across the property.

The Fun Spot is portrayed by prior geologic researchers as being underlain by Basin Deposits and Alluvium (Clark, 1981; see Figure 7), associated with the environments of the San Lorenzo River, and Neary Lagoon. It is also implicitly underlain by Purisima Formation bedrock at depth, which may be highly variable across the site, due to the fact that the ancestral San Lorenzo River may have cut several different channels across this area.

The surficial materials unconformably overlying the Purisima Formation bedrock are likely comprised of interbedded and interfingering sand, gravel, silt, clay and peat. In our opinion, the site may also be underlain by loose beach sand, based upon its' topographic position and past history of sea level low-stands and high-stands in the past hundred thousand years. Portions of the site may also be underlain by artificial fill, based upon past historical use.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future.

Flooding potential due to spill-over from San Lorenzo River and Neary Lagoon is high, with base flood elevations posted on the Federal Emergency Management Agency Flood Insurance Rate Map varying between 5 and 14 feet above mean sea level (Figure 8). Flooding potential due to storm-wave run-up may be low to moderate (Figure 8).

Potential impacts due to tsunamis is unknown, and will likely be difficult to ever pinpoint, due to the geologic complexity of characterizing the problem.

The Fun Spot site is potentially underlain at shallow depths by some or all of the following: liquefiable sand (Figure 9); compressible silt, clay, and peat; non-engineered fill; and bedrock. Potential hazards due to the presence of these earth materials include liquefaction, lateral spreading, earthquake-induced settlement and static settlement. There is a high potential for significant differential settlement to occur if the site is underlain by earth materials with divergent strength characteristics.

The lateral spreading hazard is dependent on the design and construction of the seawall southeast (and off) of the property. In the event that the seawall is inadequately designed, it may fail during a nearby large magnitude earthquake, allowing the potentially liquefiable soils it is currently retaining to laterally spread toward the bay and the ensuing free face.

Groundwater under the site will likely be shallow, salt-bearing and tidally-influenced, creating potentially corrosive foundation conditions.

Recommendations

Site-specific, detailed geotechnical engineering and engineering geology investigations should be performed to characterize the geological and geotechnical hazards and attendant risks to the proposed visitor center. The geotechnical and geologic investigations should evaluate the following hazards at a minimum:

1. Intense seismic shaking
2. Coastal flooding due to spill-over from Neary Lagoon and the San Lorenzo River, as well as storm-wave run-up
3. Liquefaction and related settlement hazards
4. The lateral spreading potential, which should include an assessment of the existing seawall southeast of the site.
5. Settlement due to consolidation of soft silt, clay or peat
6. Differential settlement across the site.
7. Corrosivity of the soil and groundwater
8. Potential problems related to old non-engineered fill

The depth to and configuration of the Purisima Formation bedrock under the site may be of paramount importance to any foundation design for structures on the property. It is nearly impossible at this stage to forecast or project the three-dimensional geometry of the bedrock surface under the site, in spite of the fact that the bedrock is outcropping in the coastal bluff along the margins of the property, due to the complex geologic history of the site. Any future geologic and geotechnical studies performed upon the site should focus upon characterizing the surficial deposits, as well as the configuration of the bedrock surface at depth.

A structural investigation of the existing seawall southeast of the site should be performed following the geotechnical investigation to determine if structural modifications are needed to bring the seawall in compliance with the applicable codes and engineering standards.

An engineer or surveyor experienced in flood surveys should establish the base flood elevations for the property.

Potential Mitigation

It is possible that the risks associated with the aforementioned hazards may be greater than ordinary for the proposed use of the site, in the absence of any mitigation. It is important that the geologic and geotechnical engineering hazards and associated risks be adequately characterized, so the future development on the site may be properly designed and constructed.

The scope of mitigation may depend upon the condition of the existing seawall, and may include structural upgrade of the seawall. Potential foundation mitigations for new development on the site may include: a rigid structural mat or pile foundation system, ground modifications such as vibro-replacement or geopiers, recompaction of existing fills, use of corrosion-resistant materials for new below-ground construction, and raising of the first floor.

The fact that the site may be subjected to flooding as well as liquefaction hazards may make development particularly problematic, since mitigation for those hazards can be at odds. Mitigation for flooding typically involves elevating the first floor of the structure above the base flood elevation determined for the project, while liquefaction hazards are typically mitigated by designing rigid slabs on grade or "pinning" the foundation to more stable bedrock at depth.

If any prospective risks are deemed to be greater than *ordinary*, as defined in Appendix A of this technical summary, they should be mitigated to lower the risk to an ordinary level

.

Probable Range Of Costs For Detailed Geotechnical Investigation - $8,000 to $15,000
Probable Range of Costs For Detailed Geologic Investigation - $3,000 to $8,000

City of Santa Cruz – Beach Boardwalk

Site Conditions

The Beach Boardwalk site is located within an existing old (nearly one hundred years old) multi-story structure along the back edge of a coastal beach, along the border of the San Lorenzo River flood plain (Figure 1C). Beach Hill, a bedrock "thumb" that protrudes through the surficial deposits in this area, is across the street from the structure, to the northwest. The structure is elevated above the beach upon a "platform" of soil being retained by an existing seawall that fronts most of the Beach Boardwalk amusement park.

The Beach Boardwalk is portrayed by Clark (1981) as being underlain by Basin Deposits and Alluvium associated with the riverine environment of San Lorenzo River (Figure 7). It is underlain by Purisima Formation bedrock at a depth of 50 feet or more, based upon the results of a recently completed consulting geotechnical engineering report by Pacific Crest Engineering (2003).

The surficial deposits unconformably overlying the Purisima Formation bedrock are likely comprised of interbedded and interfingering sand, gravel silt, clay and peat, based in part upon the results of a recent geotechnical engineering study performed at the Beach Boardwalk. In our opinion, the site may also be underlain by loose beach sand, based upon its' topographic position and past history of sea level low-stands and high-stands in the past hundred thousand years. Portions of the site may also be underlain by artificial fill, based upon the results of the recent geotechnical engineering report, and past historical uses of the site.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future. The existing structure was reportedly seismically retrofitted in the mid-1980's, according to the Beach Boardwalk staff, but we have not received documentation to verify that claim. Regardless of the past retrofit, the structure may have to be investigated and seismically retrofitted to bring it in compliance with current codes and ordinances for the proposed use of a federal visitor center.

Potential impacts due to flooding are essentially nil, since the proposed Visitors Center will be located several floors above the ground surface.

Potential impacts due to tsunamis is unknown, and will likely be difficult to ever pinpoint, due to the geologic complexity of characterizing the problem.

The Beach Boardwalk site is potentially underlain at shallow depths by some or all of the following: liquefiable sand (based partially upon the conclusions issued by in the recent consulting geotechnical engineering report; see also Figure 9), compressible silt, clay, organic-rich soil and non-engineered fill. Bedrock is about 50 feet or deeper under the existing structure, based upon the results of the recent geotechnical engineering report. Potential hazards due to these geologic conditions include liquefaction, lateral spreading, earthquake induced settlement and static settlement. The lateral spreading hazard is dependent on the design and construction of the seawall southeast of the property.

In 1906, during a large magnitude earthquake on the nearby San Andreas fault, the ground surface in the vicinity of the Beach Boardwalk was severely damaged due to intense seismic shaking, liquefaction and lateral spreading. It is unclear at this stage of our investigation if the building that was standing in the same location as the existing structure was damaged during that earthquake. The existing structure was reportedly built several months after the occurrence of the 1906 earthquake, due to a fire damaging the pre-existing building. In some sense, though, we can conclude that the existing structure has never been exposed to the intensity and duration of the seismic shaking that occurred in 1906, an event that is considered the "acid-test" for structures and seismic design in this region.

Groundwater under the site will likely be shallow, salt-bearing and tidally-influenced, creating potentially corrosive foundation conditions.

There is the potential that storm-wave erosion could impact the existing structure, depending upon the design of the existing seawall.

Recommendations

Site-specific, detailed geotechnical engineering and engineering geology investigations should be performed to characterize the geological and geotechnical hazards and attendant risks posed to locating the proposed visitor center within the existing building. The geotechnical and geologic investigations should evaluate the following hazards at a minimum:

1. The potential for intense seismic shaking to damage the existing building; a probabilistic seismic shaking hazards assessment and spectral hazards analysis may be necessary for the existing building
2. The potential for liquefaction and related settlement hazards should be characterized; their potential impacts upon the foundation of the existing building should be evaluated
3. The potential for lateral spreading to occur, which should include an assessment of the existing seawall; the potential impacts upon the foundation of the existing building should be evaluated after this hazard has been characterized
4. Settlement due to consolidation of soft silt, clay or peat; the new loading conditions that may be imposed by adding the visitor center facilities to the existing building should be evaluated; it is possible that the structure has been subjected to heavier loading in the past, depending upon types of historical uses for the building, so we recommend that the project engineers attempt to review old records which might summarize past historical uses on the site.
5. Differential settlement across the site.
6. Corrosivity of the soil and groundwater
7. Potential problems related to old non-engineered fill

A structural investigation of the existing seawall fronting the existing building along the beach might need to be performed following the geotechnical investigation to determine if structural modifications are needed to bring the seawall in compliance with the applicable codes and engineering standards.

The project geotechnical engineer and engineering geologist should work closely with a structural engineer qualified to evaluate structural seismic shaking hazards to ascertain if the existing building is in compliance with the applicable codes and engineering standards with respect to the proposed use of the facility as a federal visitor center.

Potential Mitigation

It is possible that the risks associated with the aforementioned hazards may be greater than ordinary, as defined in Appendix A of this technical summary, for the proposed use of the existing building. It is important that the geologic and geotechnical engineering hazards and associated risks be adequately characterized *with respect to the new proposed use of the building*. If the risk to the existing building is deemed to be greater than ordinary, than the identified hazards should be mitigated to lower the risk.

The scope of mitigation may depend upon the condition of the existing seawall, and may include structural upgrade of the seawall. If the risk to the existing building is deemed to be greater than ordinary, than prospective mitigation may include structural upgrades of the building, foundation modifications including underpinning piers, and the use of corrosion resistant materials for new below ground construction.

Probable Range Of Costs For Detailed Geotechnical Investigation - \$8,000 to \$10,000
Probable Range of Costs For Detailed Geologic Investigation - \$3,000 to \$8,000
Probable Range Of Costs For Geotechnical Portion Of Probabilistic Seismic Hazards Assessment And Spectral Hazards Analysis - \$4,000 to \$6,500
Probable Range Of Costs For Geologic Portion Of Probabilistic Seismic Hazards Assessment And Spectral Hazards Analysis - \$6,000 to \$7,000

County of Santa Cruz – Seacliff State Park Site

Site Conditions

The Seacliff State Beach site is located atop a relatively flat coastal bluff, elevated about 100 feet above mean sea level (Figure 1D). The base of the bluff is protected by a retaining wall and parking area, which in turn are protected by a seawall located seaward of the bluff. An open field and parking lot occupy most of the site, with a maintenance facility occupying the extreme northwestern corner of the site.

The Seacliff State Beach site is portrayed by Brabb (1997) as being underlain by uplifted coastal terrace deposits with a past sea level high-stand (Figure 10). The terrace deposits are primarily comprised of medium-dense to dense, semi-consolidated, silty and clayey sands, unconformably overlying Purisima Formation bedrock, comprised of siltstone and sandstone, as noted in the bluff exposure. A layer of expansive clay may have formed within the upper five feet of the Marine Terrace Deposits, as a result of weathering over tens of thousands of years.

Potential Geologic And Geotechnical Hazards

The site is located in an area of high seismic activity and will likely be subject to strong seismic shaking in the future.

Retreat of the coastal bluff in this area is an on-going episodic process, driven by landsliding during intense rainfall events and earthquakes, and storm-wave erosion. The sea wall located seaward of the bluff appears to have essentially eliminated the storm-wave erosion hazard, based upon our historical aerial photograph analysis. Several modes of landsliding appear to be controlling the episodic retreat of the bluff in this area. Shallow landsliding in the form of debris flows appears to episodically occur during intense periods of rainfall. Several feet of earth materials on the face of the bluff mobilizes during these events. Shallow landsliding in the form of thin (several feet thick) slabs of earth materials also appears to occur during earthquakes, such as during the 1989 Loma Prieta earthquake. Finally, there is some potential for deep-seated rotational landslides to occur during large magnitude, long duration earthquakes, such as during the 1906 earthquake.

The potential for shallow landsliding to occur within the lifetime of the proposed visitor center is high; the attendant risk is dependant upon the distance the visitor center is located from the top of the coastal bluff. The potential for deep-seated landsliding to occur with the lifetime of the proposed visitor center is moderate; as with shallow landslding, the attendant risk is dependant upon the distance with respect to top of the coastal bluff.

Recommendations

Visitor Center Set Back Greater Than 100 Feet From Top Of Bluff

For development located greater than 100 feet from the top of the bluff, we recommend that a detailed site-specific geotechnical engineering investigation be performed to characterize the stratigraphy and engineering properties of the earth materials that underlie the site. The investigation should include the following analyses:

1. Expansive potential of the foundation zone soil.
2. Settlement potential
3. Corrosivity of the soil

If the constructed facility is a one-story facility, and designed and constructed in compliance with the current California Building Code, no special seismic shaking analyses may be necessary.

Visitor Center Set Back Less Than 100 Feet From Top Of Bluff

For development located less than 100 feet from the top of the bluff, we recommend that detailed site-specific geotechnical engineering and engineering geology investigations be performed to characterize the stratigraphy and engineering properties of the earth materials that underlie the site, as well as the bluff-retreat hazards. The investigation should include the following analyses:

1. Characterization of bluff retreat hazards, including a quantitative slope stability analysis of the bluff
2. Expansive potential of the foundation zone soil
3. Settlement potential
4. Corrosivity of the soil
5. Alternative foundation and sub-grade preparation measures

If the constructed facility is a one-story facility, and designed and constructed in compliance with the current California Building Code, no special seismic shaking analyses may be necessary.

Potential Mitigation

Mitigation of the bluff erosion and landsliding hazards can easily be accomplished by setting the visitor center back from the top of the bluff. In our opinion, if the visitor center is setback 100 feet or more from the top of the bluff, geologic studies addressing the stability of the bluff will be unnecessary. Facilities located between 50 and 100 feet from the top of the bluff may have to be designed with special foundation elements to take future bluff retreat into account. Facilities located within 50 feet of the top of the bluff will likely have to be designed with special foundation elements to mitigate the impacts of future bluff retreat. Adverse effects due to the presence of expansive clay soil, if present, may be mitigated by the removal of the clay or by foundation design.

If any prospective risks are deemed to be greater than *ordinary*, as defined in Appendix A of this technical summary, they should be mitigated to lower the risk to an ordinary level.

Probable Range Of Costs

Visitor Center Set Back Greater Than 100 Feet From Top Of Bluff
Probable Range Of Costs For Detailed Geotechnical Investigation - $5,000 to $10,000
No geologic investigation may be necessary.

Visitor Center Set Back Less Than 100 Feet From Top Of Bluff
Probable Range Of Costs For Detailed Geotechnical Investigation - $5,000 to $10,000
Probable Range of Costs For Detailed Geologic Investigation - $6,000 to $8,000

APPENDIX A

SCALE OF ACCEPTABLE RISKS FROM GEOLOGIC HAZARDS

SCALE OF ACCEPTABLE RISKS FROM SEISMIC GEOLOGIC HAZARDS

Risk Level	Structure Types	Extra Project Cost Probably Required to Reduce Risk to an Acceptable Level
Extremely low[1]	Structures whose continued functioning is critical, or whose failure might be catastrophic: nuclear reactors, large dams, power intake systems, plants manufacturing or storing explosives or toxic materials.	No set percentage (whatever is required for maximum attainable safety).
Slightly higher than under "Extremely low" level.[1]	Structures whose use is critically needed after a disaster: important utility centers; hospitals; fire, police and emergency communication facilities; fire station; and critical transportation elements such as bridges and overpasses; also dams.	5 to 25 percent of project cost.[2]
Lowest possible risk to occupants of the structure.[3]	Structures of high occupancy, or whose use after a disaster would be particularly convenient: schools, churches, theaters, large hotels, and other high rise buildings housing large numbers of people, other places normally attracting large concentrations of people, civic buildings such as fire stations, secondary utility structures, extremely large commercial enterprises, most roads, alternative or non-critical bridges and overpasses.	5 to 15 percent of project cost.[4]
An "ordinary" level of risk to occupants of the structure.[3,5]	The vast majority of structures: most commercial and industrial buildings, small hotels and apartment buildings, and single family residences.	1 to 2 percent of project cost, in most cases (2 to 10 percent of project cost in a minority of cases).[4]

1 Failure of a single structure may affect substantial populations.
2 These additional percentages are based on the assumptions that the base cost is the total cost of the building or other facility when ready for occupancy. In addition, it is assumed that the structure would have been designed and built in accordance with current California practice. Moreover, the estimated additional cost presumes that structures in this acceptable risk category are to embody sufficient safety to remain functional following an earthquake.
3 Failure of a single structure would affect primarily only the occupants.
4 These additional percentages are based on the assumption that the base cost is the total cost of the building or facility when ready for occupancy. In addition, it is assumed that the structures would have been designed and built in accordance with current California practice. Moreover the estimated additional cost presumes that structures in this acceptable-risk category are to be sufficiently safe to give reasonable assurance of preventing injury or loss of life during and following an earthquake, but otherwise not necessarily to remain functional.
5 "Ordinary risk": Resist minor earthquakes without damage: resist moderate earthquakes without structural damage, but with some non-structural damage; resist major earthquakes of the intensity or severity of the strongest experienced in California, without collapse, but with some structural damage as well as non-structural damage. In most structures it is expected that structural damage, even in a major earthquake, could be limited to repairable damage. (Structural Engineers Association of California)

Source: *Meeting the Earthquake,* Joint Committee on Seismic Safety of the California Legislature, Jan. 1974, p.9.

SCALE OF ACCEPTABLE RISKS FROM NON-SEISMIC GEOLOGIC HAZARDS[6]

Risk Level	Structure Type	Risk Characteristics
Extremely low risk	Structures whose continued functioning is critical, or whose failure might be catastrophic: nuclear reactors, large dams, power intake systems, plants manufacturing or storing explosives or toxic materials.	1. Failure affects substantial populations, risk nearly equals nearly zero.
Very low risk	Structures whose use is critically needed after a disaster: important utility centers; hospitals; fire, police and emergency communication facilities; fire station; and critical transportation elements such as bridges and overpasses; also dams.	1. Failure affects substantial populations. Risk slightly higher than 1 above.
Low risk	Structures of high occupancy, or whose use after a disaster would be particularly convenient: schools, churches, theaters, large hotels, and other high rise buildings housing large numbers of people, other places normally attracting large concentrations of people, civic buildings such as fire stations, secondary utility structures, extremely large commercial enterprises, most roads, alternative or non-critical bridges and overpasses.	1. Failure of a single structure would affect primarily only the occupants.
"Ordinary" risk	The vast majority of structures: most commercial and industrial buildings, small hotels and apartment buildings, and single family residences.	1. Failure only affects owners /occupants of a structure rather than a substantial population. 2. No significant potential for loss of life or serious physical injury. 3. Risk level is similar or comparable to other ordinary risks (including seismic risks) to citizens of coastal California. 4. No collapse of structures; structural damage limited to repairable damage in most cases. This degree of damage is unlikely as a result of storms with a repeat time of 50 years or less.
Moderate risk	Fences, driveways, non-habitable structures, detached retaining walls, sanitary landfills, recreation areas and open space.	1. Structure is not occupied or occupied infrequently. 2. Low probability of physical injury. 3. Moderate probability of collapse.

[6] Non-seismic geologic hazards include flooding, landslides, erosion, wave runup and sinkhole collapse

APPENDIX B

FIGURES